
5 Case study: Validation

5.1 Preamble

The energy saving strategies developed and simulated in Chapter 4, were implemented on the mines as part of energy saving projects funded by Eskom and the clients. The results obtained post-implementation of the strategies, were used to validate the electrical energy savings that were found through simulation.

5.2 Validation: Mine A

5.2.1 Installation

Variable speed drives (VSDs) displayed in *Table 14* were installed on the pre-cooling tower pumps, transfer pumps, evaporator pumps and condenser pumps. Due to specific equipment preference of the client, the cost of the drives exceeded the initial budgeted amount allowing for all the drives except three of the condenser VSDs to be installed.

Table 14: Mine A - VSDs installed

Description	Quantity	Application
40 kW Schneider VSD	2	Pre-cool transfer pumps
70 kW Schneider VSD	2	Pre-cool feed pumps
75 kW Schneider VSD	3	BAC pumps
110 kW Schneider VSD	6	Evaporator pumps
200 kW Schneider VSD	3	Condenser pumps

The mine cooling system layout after the project implementation can be seen in *Figure 22*. To avoid clutter, the instrumentation communication lines between the programmable logic controllers (PLCs) and VSDs are not displayed in this figure.

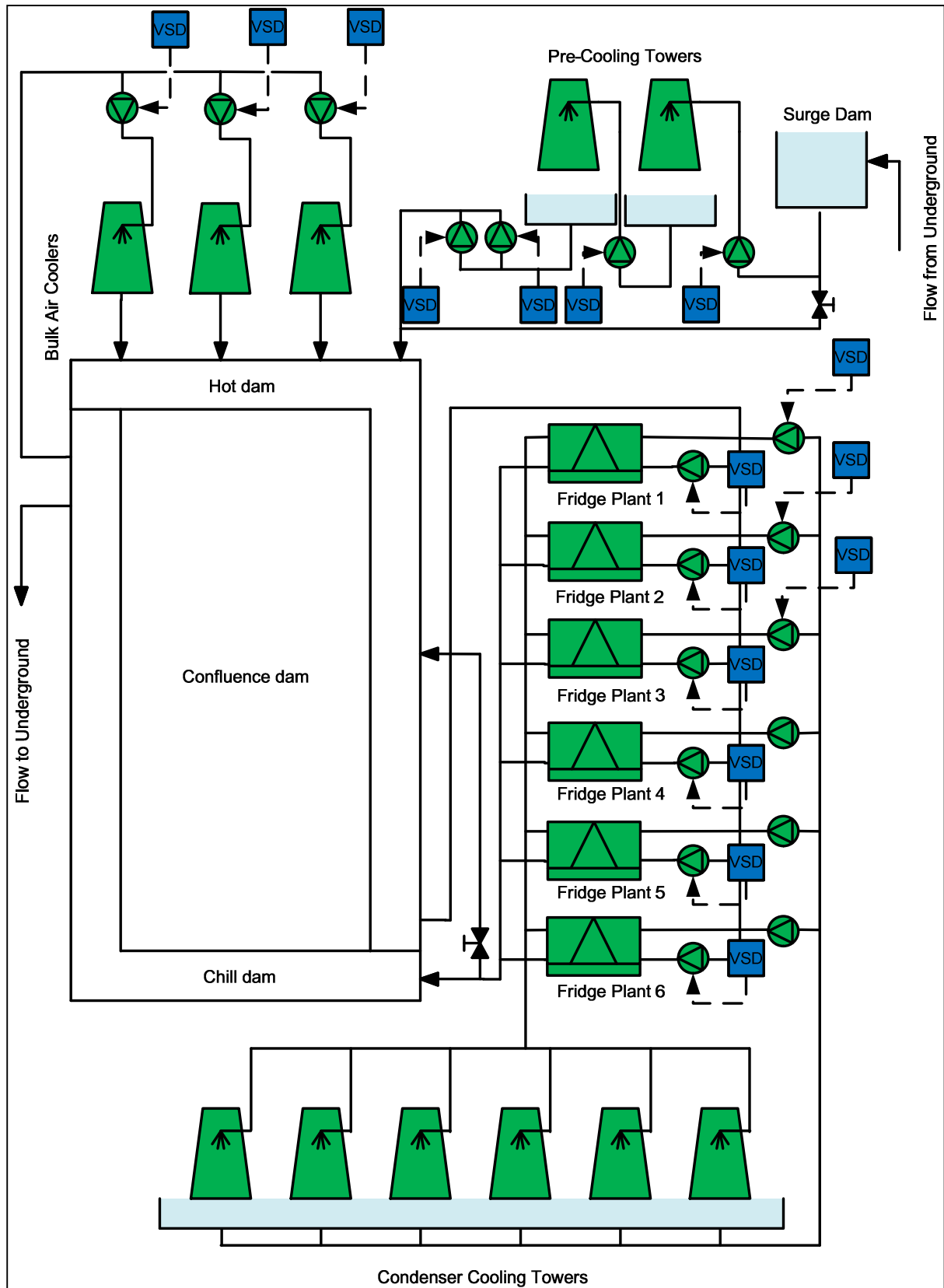


Figure 22: Mine A - cooling system layout after implementation

A weather station measuring the ambient temperature and humidity was installed for purpose of the BAC flow control. This unit automatically calculates the enthalpy using these parameters. The weather station, as it was installed, is shown in *Figure 23*.



Figure 23: Mine A - weather station

The existing power cables to the pump motors were used. Only short extensions of new cable were required to connect the VSDs. The VSDs were connected between the existing motor control centre (MCC) and the motor itself, enabling isolation to the entire VSD panel in the event of maintenance. A decommissioned ice plant's MCC panels inside the refrigeration plant room were removed to create sufficient space to install the bulk air cooler (BAC), evaporator and condenser VSDs, as shown in *Figure 24*. The installed VSDs are displayed in *Figure 25* and *Figure 26*.

The room housing the pre-cooling tower and transfer pumps had sufficient space next to the existing MCC panels to install the four VSDs. Their control was programmed onto the local pre-cooling PLC. This installation is presented in *Figure 27*.



Figure 24: Mine A - location where VSDs will be installed



Figure 25: Mine A - installed BAC, evaporator and condenser VSDs (1)



Figure 26: Mine A - installed BAC, evaporator and condenser VSDs (2)



Figure 27: Mine A - pre-cooling feed and transfer pump VSDs

The existing local refrigeration machine PLCs were used to control the condenser and evaporator VSDs with control modifications made to the PLC program. This was performed by the appointed contractor.

The installation commenced during September 2011 and was completed early January 2012. The installation took longer than expected due to the limited availability of refrigeration machines during the summer months. To prevent production losses, only one machine at a time was made available to work on for short periods during the afternoons and over weekends.

5.2.2 Commissioning

After completing the installation and programming of the PLCs early in January 2012, the remainder of January was used to commission the system.

The valve between the pre-cool transfer pumps and the hot dam passing water back into the surge dam were decommissioned and closed. The valve between the chill dam and the hot dam previously used to pass chill water back to the hot dam was also closed and decommissioned.

The first VSDs to be commissioned were those of the BAC. The flow restriction valves situated between the pumps and the towers, used to calibrate the flow to design flow in the past, were fully opened and are shown in *Figure 28*. The flow through each pump was measured and calibrated using a portable ultrasonic flow meter where the ultrasonic probes are secured, as shown in *Figure 29*. *Figure 30* presents the computer unit, displaying one of the flows during the calibration process.

The maximum frequency of the VSDs was calibrated to supply a design flow of 250 l/s through each of the three towers. Subsequently this was programmed to be the flow for ambient enthalpy values of 70 kJ/kg and higher. The minimum VSD frequency was calibrated for a zero water flow condition and corresponds to 25 kJ/kg ambient enthalpy or lower. The minimum frequency determined was sufficient to overcome the head of the tower manifold pipes without pouring water through the tower. This static operation was detrimental for the pumps and therefore the PLC program was adapted to allow a step change

from the minimum frequency to 0 Hz. This implies that the VSD frequency will approach the set minimum as the ambient enthalpy approaches 25 kJ/kg and then jump to 0 Hz if the enthalpy decreases below 25 kJ/kg.



Figure 28: Mine A - BAC flow calibration valve



Figure 29: Mine A - ultrasonic flow meter probe mounting

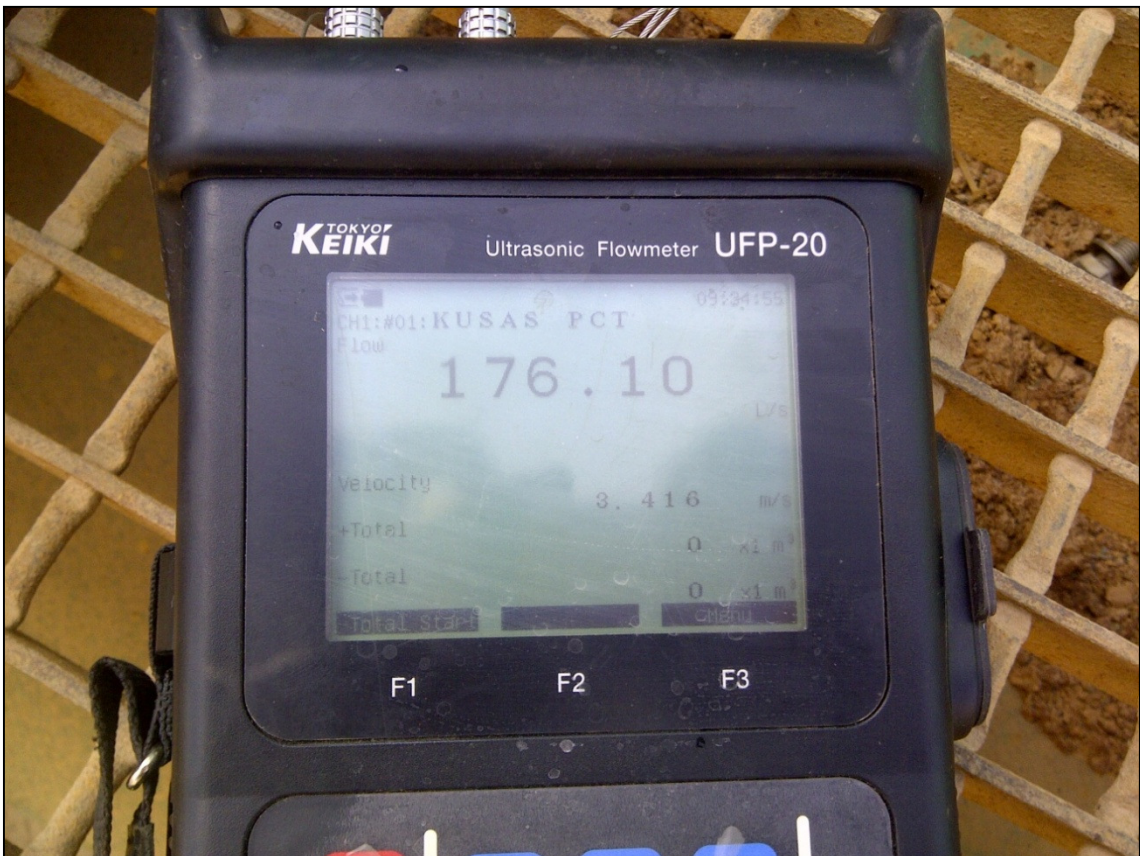


Figure 30: Ultrasonic flow meter computer unit

The pre-cooling tower supply and transfer pumps' VSDs were the next components to be commissioned. This included opening the flow restriction valves fully. The two transfer pumps as well as the two pre-cool tower supply pumps along with one of their valves can be seen in *Figure 31*.



Figure 31: Mine A - transfer and pre-cool supply pumps and valves

Thereafter, the Evaporator and Condenser VSDs of each machine were commissioned one at a time. All the flow restricting valves between the pumps and machines were opened fully except for the condenser valves on the three machines without condenser VSDs. The minimum and maximum frequencies were determined. This was achieved by monitoring the flow on each machine's PLC and calibrating it to control within the allowable flow range for each component without entering a high or low flow trip condition. Each machine was uniquely calibrated with only a small variance of the minimum and maximum frequencies. In *Table 15* the average minimum and maximum operating frequencies are displayed along with its corresponding water flow rate.

Table 15: Mine A - minimum and maximum VSD frequencies and corresponding water flow

VSD	Frequency [Hz]		Flow [l/s]	
	Minimum	Maximum	Minimum	Maximum
BAC	31	42	0	250
Pre-cooling supply	0	50	0	200
Pre-cooling transfer	0	50	0	200
Evaporator	34	43	180	250
Condenser	36	44	360	450

5.2.3 Energy saving verification

After commissioning was completed in January 2012 the project performance assessment commenced in February 2012 and continued until the end of April 2012. As shown in *Figure 32*, the average daily power consumption of the performance assessment period of 2012 was measured against the average daily power consumption for the same period of time during 2010 which was used as the baseline.

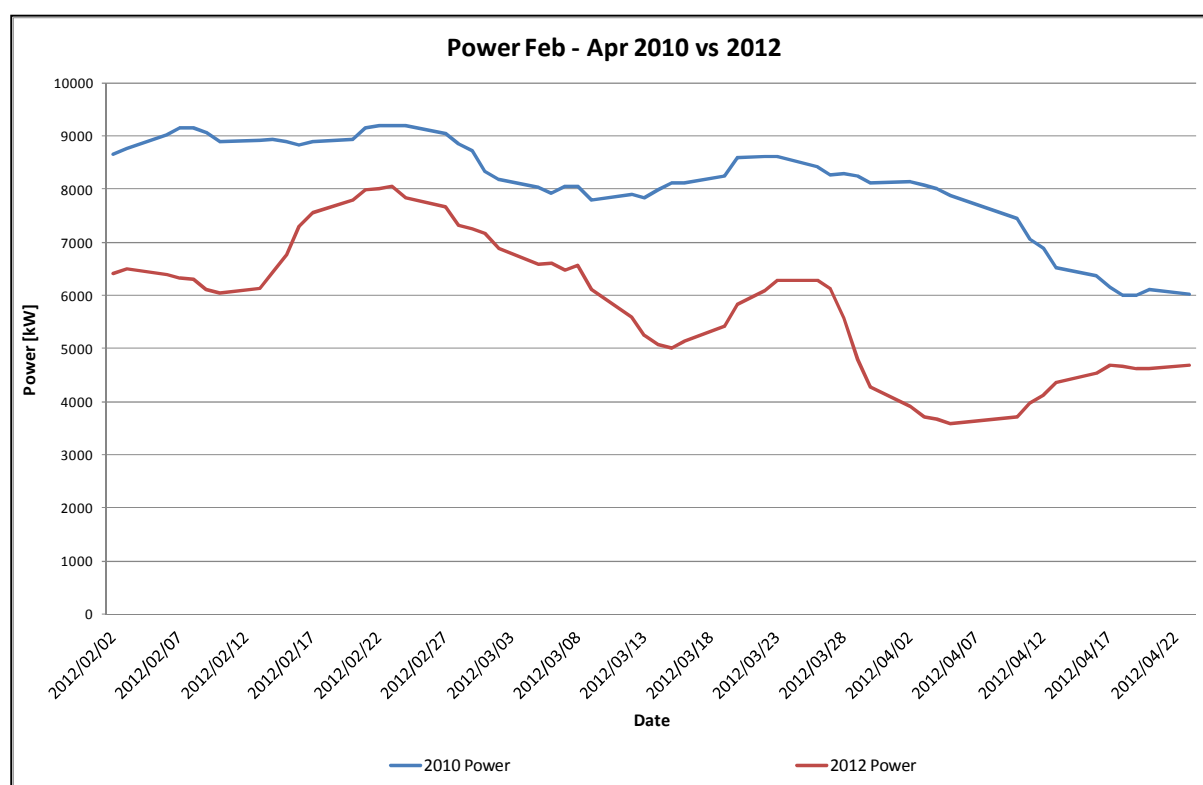


Figure 32: Mine A - refrigeration plant power for February to April 2010 and 2012

Two of the primary parameters influencing the fluctuation in power consumption of the refrigeration machines are the water flow sent underground and the ambient enthalpy. *Figure*

33 presents the power consumption for the assessment period including the ambient enthalpy. *Figure 34* also shows the power, together with the water flow, which was only recorded since early in March 2012.

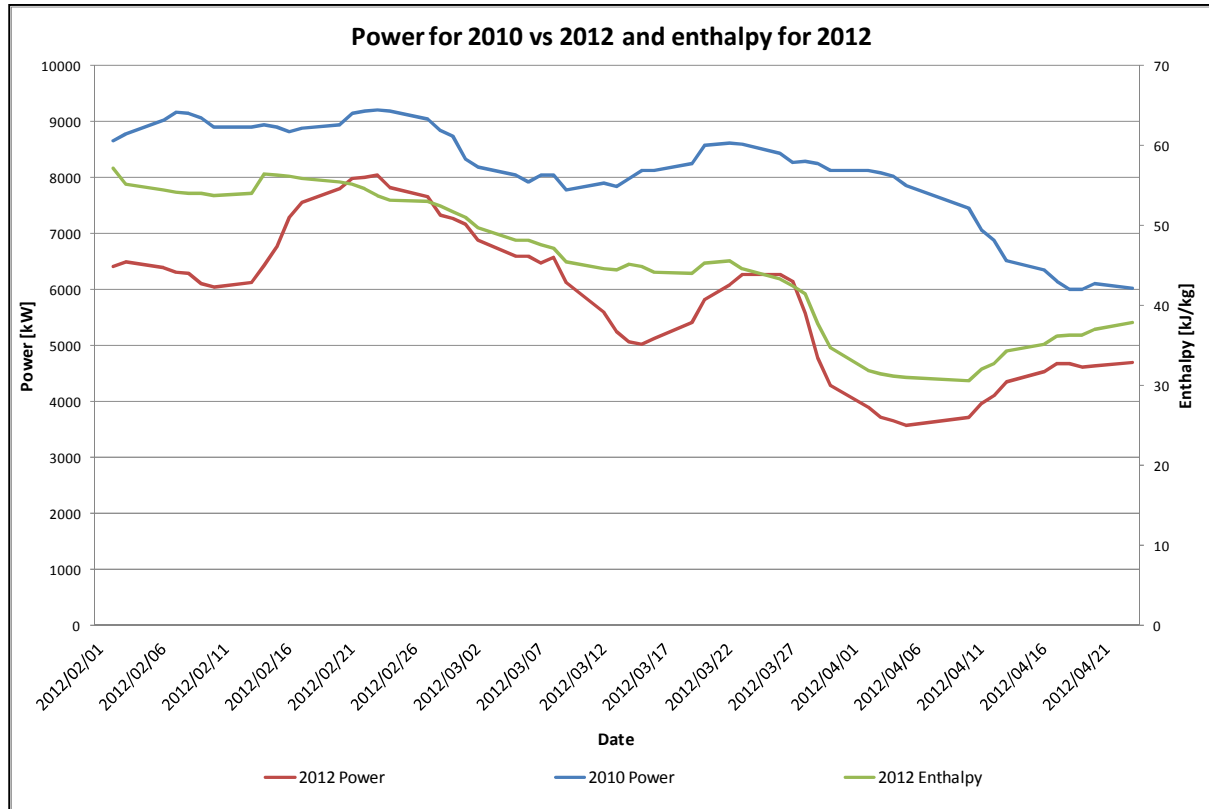


Figure 33: Mine A - refrigeration plant power for February to April 2010, 2012 and ambient enthalpy

From *Figure 33* it is apparent that the power consumption decreases as the ambient enthalpy decreases. From the beginning of 2012 until halfway through February 2012 the mine was only partially operational due to a fatality during December 2012, resulting in a reduction of the electrical energy used during February 2012.

The decrease in power between 2012/03/07 and 2012/03/22 is a result of the decrease in water sent down the shaft as can be seen in *Figure 34*. The enthalpy remains fairly constant during that same period. During the period 2012/03/27 to 2012/04/11, the reduced consumption is attributed to a combination of water decrease and a decrease in the ambient enthalpy.

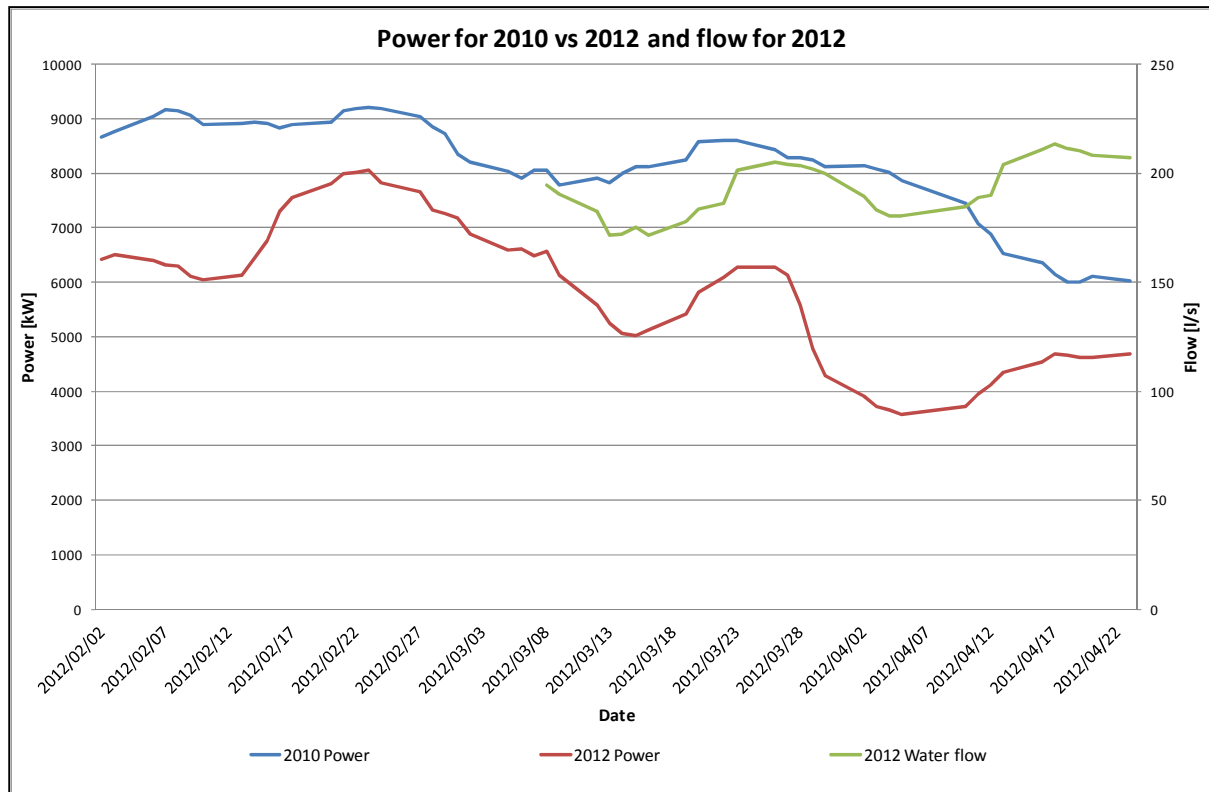


Figure 34: Mine A - refrigeration plant power for February to April 2010, 2012 and water flow down the shaft

The flow required for the mining operations can fluctuate dynamically while the enthalpy fluctuates as the seasons change. This system responds very well to these changes, reducing the overall refrigeration power consumption.

Table 16 displays the saving results. An average electrical energy saving for the period February to April 2012 of 2.3 MW was realised, while the suggested simulated saving for the same period was 2MW. This resulted in an over performance of 13 % and an energy saving of approximately 30 % on the refrigeration system. This over performance can be reflected as a result of a 10% safety margin that was added to the final design and the additional 3% due to close operational monitoring and fine tuning done to the system, not incorporated in the simulation model, during the performance assessment period.

Table 16: Mine A - baseline, proposed savings and savings achieved

Month	2010 measured baseline [kW]	2012 Measured power [kW]	Suggested simulated saving [kW]	Saving achieved [kW]	% Saving
February	8840.05	6826.08	1447.54	2013.98	22.78
March	8400.80	6279.90	1872.96	2120.90	25.25
April	7092.52	4276.29	2553.60	2816.23	39.71
Average	8111.13	5794.09	1958.03	2317.04	29.25

5.3 Validation: Mine B

5.3.1 Installation and commissioning

A private company was contracted to install new pre-cooling towers due to the poor condition of the fill material and the structural integrity of the existing towers.

The entire replacement of the towers enabled the use of a splash type of fill material. A higher tower was required to accommodate the new fill materials which are larger in volume per heat transfer area as stated in Section 2.3.1.

The principal challenge of the installation was to decommission one bank of towers and build the new tower without disrupting mine production. The installation commenced in July 2011 and was completed by the end of September 2011. Due to the installation taking place mostly during winter time the BACs were not in operation, having a lower demand for chilled water as a result. This enabled the contractors to run all the water demanded through one bank of cooling towers at a time, while replacing the other.

Figure 35 to Figure 37 shows some photographs taken during the dismantling process and highlights the dilapidated condition of the fill material as well as the depraved condition of the structure.



Figure 35: Mine B - existing pre-cooling tower structure (1)



Figure 36: Mine B - existing pre-cooling tower structure (2)



Figure 37: Mine B - existing pre-cooling tower fill material

Figure 37 shows the fill material removed from the tower. It is impossible for any water to flow in some of the flutes causing significant reductions in the heat transfer potential. The poor condition of the water at Mine B would necessitate frequent replacement of the fill material. Quarterly replacements of the fill material could be required, making it very costly.

The cooling tower company suggested the use of a splash type of fill which was uniquely designed by them. *Figure 38* shows a sample of the fill used in the new towers. This fill is more compact than the regularly available splash fill available on the market which can be seen in *Figure 39*. As the new fill was denser than the regular splash fill, only a small increase in tower size was significant. Structural documentation was therefore not required as the new tower did not exceed the height restriction that would have required special engineering design and approval.

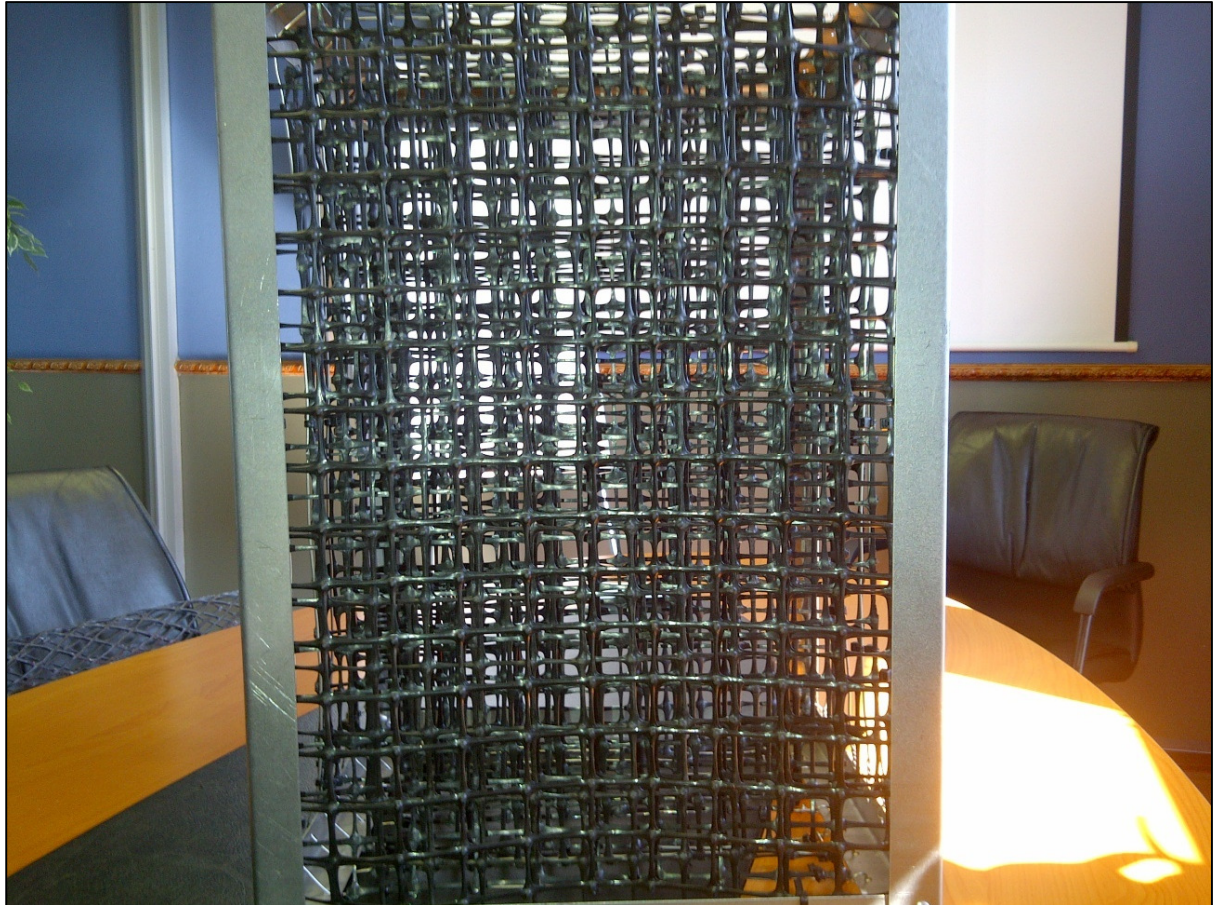


Figure 38: Splash fill used

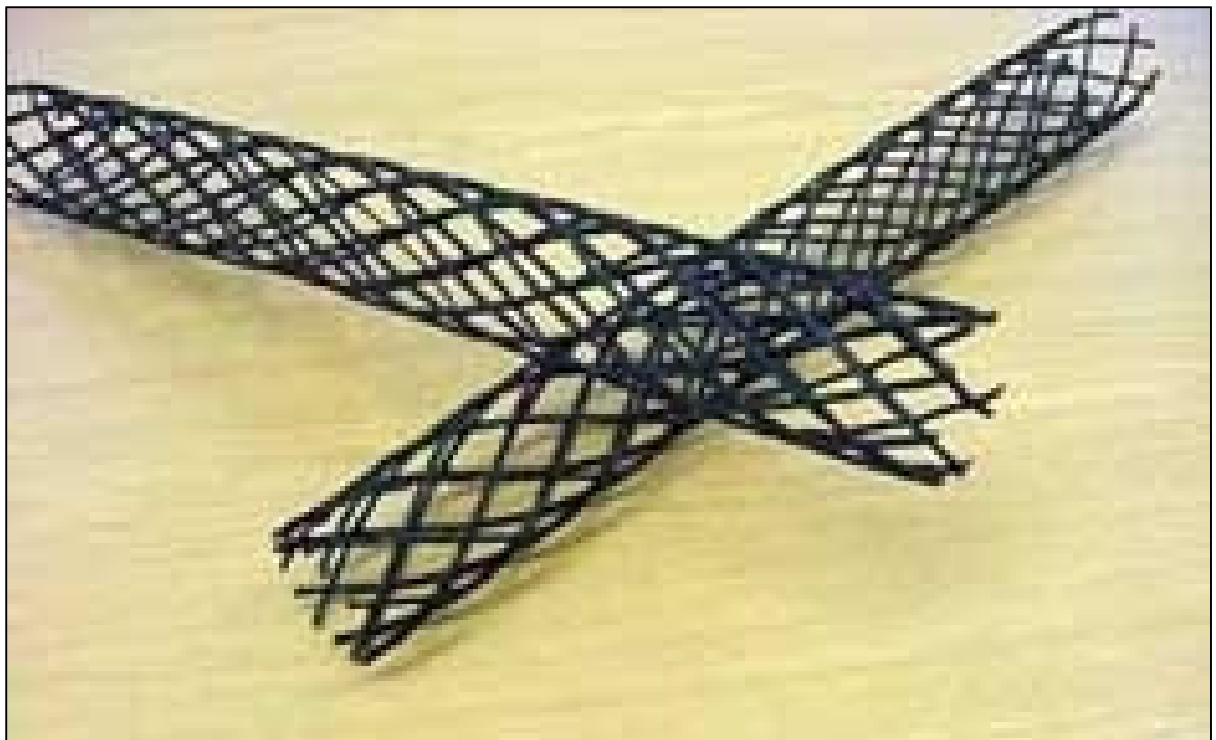


Figure 39: Splash tube fill

Figure 40 and *Figure 41* are photographs taken during the assembly of one of the new banks of four towers. The cooling tower company suggested using four 5.5 kW motors with smaller fans per cooling tower instead of one 22 kW motor with a larger fan. The reason for this is to simplify maintenance procedures. The operation of the cooling towers will be less compromised when a single motor is shut down as there will still be three motors running. A further advantage is that smaller motors can easily be changed by two people using a small hoisting rig. The performance of the cooling tower can be maintained at 75 % in the event of one fan becoming unserviceable.

The material used to construct the tower frame was changed from galvanised steel to stainless steel to prolong the integrity of the construction under the poor water conditions at the mine. The assembly of the first towers' structure is shown in *Figure 40*.



Figure 40: Mine B - new pre-cooling tower structure

Figure 41 shows the first bank of new pre-cooling towers completed.



Figure 41: Mine B - new pre-cooling towers bank 1

After the completion of the first bank of towers all the required process water was pumped through the new towers to allow for the dismantling and construction of the second bank.

5.3.2 Cooling tower performance verification

After the new cooling towers were installed and fully operational, their cooling performance was verified by measuring the water inlet and outlet temperatures along with the ambient enthalpy. The water flow through the towers was measured using an ultrasonic portable flow meter.

The measured inlet temperature and ambient conditions were used as input values to the simulation model. Using these values, the model could calculate the output temperature relative to the specific input conditions. This was subsequently compared to the measured output temperature to verify the accuracy of the simulation model.

The measured and simulated results are presented in *Table 17*.

Table 17: Pre-cooling tower measured data of new towers

Description	Value
Flow [l/s]	308
Inlet temperature [°C]	31.38
Outlet temperature [°C]	21.58
Simulated outlet temperature [°C]	22.15
Ambient temperature [°C]	26.95
Ambient relative humidity [%]	49.6

A discrepancy of 2.6 % relative to the measured outlet temperature was obtained between the measured and simulated outlet conditions. The discrepancy is on the conservative side and might be due to the cooling tower manufacturers incorporating small additional safety margins according to the design criteria supplied to them, it is concluded that the electrical energy saving on the refrigeration system would be 1.3MW, when using an average refrigeration unit COP of 6 as stipulated in *Table 10*, and corresponds well to the saving suggested in *Table 13*.

5.4 Conclusion

The case studies validated in this chapter both realised a small percentage of over-performance in comparison to the simulation model. The over performance in the first case is suggested to be due to a safety margin of 10% applied to the final system design with close monitoring and fine tuning accounting for the other 3% of over performance. The over performance of the second case is suggested to be due to additional safety margins incorporated by the cooling tower manufacturing company. These results are satisfactory as a conservative approach which will ensure that unrealistic savings will not be offered to either the client or Eskom. An average overall conservative error is considered to be an acceptable safety margin for contractual purposes.